Acceptability of Flight Deck-Based Interval Management Crew Procedures

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The Interval Management for Near-term Operations Validation of Acceptability (IM-NOVA) experiment was conducted at the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) in support of the NASA Next Generation Air Transportation System (NextGen) Airspace Systems Program's Air Traffic Management Technology Demonstration - 1 (ATD-1). ATD-1 is intended to showcase an integrated set of technologies that provide an efficient arrival solution for managing aircraft using NextGen surveillance, navigation, procedures, and automation for both airborne and ground-based systems. The goal of the IM-NOVA experiment was to assess if procedures outlined by the ATD-1 Concept of Operations, when used with a minimum set of Flight deck-based Interval Management (FIM) equipment and a prototype crew interface, were acceptable to and feasible for use by flight crews in a voice communications environment. To investigate an integrated arrival solution using ground-based air traffic control tools and aircraft automatic dependent surveillance broadcast (ADS-B) tools, the LaRC FIM system and the Traffic Management Advisor with Terminal Metering and Controller Managed Spacing tools developed at the NASA Ames Research Center (ARC) were integrated in LaRC's Air Traffic Operations Laboratory. Data were collected from 10 crews of current, qualified 757/767 pilots asked to fly a high-fidelity, fixed based simulator during scenarios conducted within an airspace environment modeled on the Dallas-Fort Worth (DFW) Terminal Radar Approach Control area. The aircraft simulator was equipped with the Airborne Spacing for Terminal Area Routes algorithm and a FIM crew interface consisting of electronic flight bags and ADS-B guidance displays. Researchers used "pseudo-pilot" stations to control 24 simulated aircraft that provided multiple air traffic flows into DFW, and recently retired DFW air traffic controllers served as confederate Center, Feeder, Final, and Tower controllers. Pilot participant feedback indicated that the procedures used by flight crews to receive and execute interval management (IM) clearances in a voice communications environment were logical, easy to follow, did not contain any missing or extraneous steps, and required the use of an acceptable level of workload. The majority of the pilot participants found the IM concept, in addition to the proposed FIM crew procedures, to be acceptable and indicated that the ATD-1 procedures can be successfully executed in a near-term NextGen environment.

Nomenclature

ADS-B	=	Automatic Display Surveillance – Broadcast
AGD	=	ADS-B Guidance Display
ARC	=	Ames Research Center
ASTAR	=	Airborne Spacing for Terminal Area Routes

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ASTOR	=	Aircraft Simulation for Traffic Operations Research
ATC	=	Air Traffic Control
ATD-1	=	Air Traffic Management Technology Demonstration – 1
ATOL	=	Air Traffic Operations Laboratory
CAS	=	Calibrated Airspeed
ConOps	=	Concept of Operations
CMS	=	Controller Managed Spacing
DFW	=	Dallas-Fort Worth
DSR	=	Display System Replacement
EFB	=	Electronic Flight Bag
ETA	=	Estimated Time of Arrival
FAA	=	Federal Aviation Administration
FAF	=	Final Approach Fix
FDB	=	Full Data Block
FIM	=	Flight deck-based Interval Management
FMS	=	Flight Management System
IFD	=	Integration Flight Deck
IM	=	Interval Management
LaRC	=	Langley Research Center
MACS	=	Multi Aircraft Control System
MCH	=	Modified Cooper-Harper
N	=	number of observations
NAS	=	National Airspace System
NASA	=	National Aeronautics and Space Administration
NextGen	=	Next Generation Air Transportation System
OPD	=	Optimized Profile Descent
p	=	*p*-value (note: a value < 0.05 indicates a statistically significant difference between sample means)
PF	=	pilot flying
PM	=	pilot monitoring
RNAV	=	Area Navigation
SD	=	standard deviation
SOP	=	Standard Operating Procedures
STA	=	Scheduled Time of Arrival
STARS	=	Standard Terminal Automation Replacement System
TMA-TM	=	Traffic Management Advisor with Terminal Metering
TOD	=	top-of-descent
TRACON	=	Terminal Radar Approach Control

I. Introduction

The 2011-2031 Federal Aviation Administration (FAA) Aerospace Forecast predicts that commercial aviation will grow on average 3.7% throughout the next 20 years, with the number of revenue passenger miles doubling by 2031.[1] Arrivals into high-density airports, especially during peak traffic periods and inclement weather, will experience significant inefficiencies due to the use of miles-in-trail procedures and step-down descents. Use of these current procedures contributes to reduced airport capacity, increased controller workload, increased arrival delay, and increased aircraft fuel burn, emissions, and noise. While advanced arrival procedures exist at a limited number of sites, oftentimes these procedures are underutilized due to the lack of supporting scheduling and spacing technologies.

NASA's NextGen Airspace Systems Program is co-sponsoring, in partnership with the FAA, an effort referred to as ATD-1 that combines advanced arrival scheduling, controller decision support tools, and aircraft avionics in order to enable efficient arrival operations in high-density terminal airspace.[2,3] To achieve increased fuel efficiency during periods of high traffic demand, aircraft will use Area Navigation (RNAV) routes extending from en route airspace to the runway in conjunction with Optimized Profile Descent (OPD) procedures that provide a continuous descent approach. The intent is to allow flight crews to use their onboard Flight Management System (FMS) capabilities to fly from cruise altitude to landing, employing fuel-efficient vertical profiles, and without needing controllers to provide radar vectors to the final approach course.

ATD-1's first phase will culminate in a field trial that will increase understanding of the necessary equipment standards, aircraft certification guidance, and operational approvals, as well as the potential benefits and costs, associated with widespread implementation of Automatic Display Surveillance – Broadcast (ADS-B) as the future surveillance source for the National Airspace System (NAS). As part of initial preparations for the ATD-1 field trial, the IM-NOVA experiment was conducted at NASA LaRC in order to assess if procedures outlined by the ATD-1 Concept of Operations (ConOps),[4] when used with a minimum set of FIM equipment and a prototype crew interface, were acceptable to and feasible for use by flight crews operating within a voice communications environment.

The IM-NOVA experiment served as the first successful integration of the NASA LaRC and ARC flight- and ground-based IM technology systems using a full-mission flight-cab simulator. The integrated set of technologies included the LaRC FIM system and the ARC TMA-TM and CMS tools. The three core components of the ATD-1 integrated system are described below:

- Traffic Management Advisor with Terminal Metering (TMA-TM) generates precise time-based schedules to the runway and merge points within the terminal area.
- Controller Managed Spacing (CMS) decision support tools provide air traffic controllers with speed advisories and other information needed to meet the schedule.
- Flight deck-based Interval Management (FIM) avionics and procedures allow flight crews to adjust their speed to achieve precise relative spacing.

The Traffic Management Advisor (TMA) was developed at ARC and is currently utilized by Air Route Traffic Control Centers nationwide to determine appropriate arrival schedules.[5] TMA-TM is an enhanced form of TMA that includes terminal area metering and enables the use of more efficient arrival procedures. CMS decision support tools, also developed at ARC, provide controllers with information needed to achieve arrival schedule conformance through the use of speed commands rather than through the use of tactical vectoring.[6,7] Results of investigations conducted to examine the use of TMA-TM in conjunction with CMS tools indicate that airport throughput increases with the use of these ground-based technologies.[8-11]

FIM is an airborne spacing concept in which the flight crew is responsible for flying their aircraft at a speed that achieves their assigned time-based spacing interval behind a target aircraft, while Air Traffic Control (ATC) remains responsible for ensuring that all aircraft maintain safe separation. Typically, ATC designates a spacing buffer in addition to the separation requirement to ensure that separation is always maintained. The goal of airborne spacing is to decrease this spacing buffer by decreasing the variability of the time error associated with an aircraft's arrival at a specific point along its arrival route. The precise merging and spacing enabled by FIM avionics and flight crew procedures reduces excess spacing buffers and results in higher terminal throughput. Studies conducted by MITRE,[12-14] EUROCONTROL,[15-18] and NASA LaRC[19-21] have demonstrated an increase in efficiency through the use of FIM operations.

While investigations conducted at NASA ARC indicate that the ATD-1 concept is viable,[22-24] the LaRC IM-NOVA experiment assessed if the proposed ATD-1 procedures, when used with the integrated ATD-1 technologies and a prototype FIM crew interface, were acceptable to and feasible for use by flight crews in a voice communications environment. This paper describes the experiment's methodology and the results of the evaluation of the FIM crew procedures' acceptability. Details regarding the results associated with the evaluation of the FIM crew procedures' feasibility are presented in a companion paper.[25]

II. Methodology

A. Experiment and Scenario Design

To assess if the proposed ATD-1 procedures were acceptable to and feasible for use by flight crews when the procedures were used with a minimum set of FIM equipment and a prototype crew interface in a voice communications environment, data were collected from current, qualified 757/767 pilot participants asked to fly a high-fidelity, fixed based simulator during scenarios conducted within an airspace environment modeled on the DFW Terminal Radar Approach Control (TRACON) area. Each experiment scenario consisted of multiple air traffic flows involving 25 arrival aircraft flying into DFW airport and landing on runways 17C and 18R. All aircraft flew optimized profile descents (OPD) to the Instrument Landing System (ILS) intercept to the runway threshold.

Some aircraft initialized in level cruise and flew the full arrival and approach to the runway, while others initialized in descent and flew only a portion of the arrival before flying the approach. One of the arrival aircraft employed a high-fidelity, fixed base simulator with pilot participants operating as a two-person crew. This simulator was equipped with NASA LaRC's airborne spacing algorithm, Airborne Spacing for Terminal Area Routes (ASTAR)[26] (version 11.06.22), and a prototype FIM crew interface (shown in Figures 1 and 2). The remaining 24 arrival aircraft were flown by two researcher pseudo-pilots, each of whom used a graphical user interface to control multiple medium-fidelity aircraft simulators. To provide a realistic traffic environment, each scenario also included 25 departure aircraft. Recently retired DFW air traffic controllers served as confederate Center, Feeder, Final, and Tower controllers issuing speed commands, vectors, and IM clearances.

When performing FIM operations, pilot participants were expected to use ASTAR-provided speed guidance whenever possible. This speed guidance is designed such that the FIM, or spacing, aircraft will achieve the assigned spacing goal behind its lead, or target, aircraft at a predefined achieve-by point while remaining within 10% of the optimized profile airspeed. In this experiment, the final approach fix (FAF) served as the FIM aircraft's achieve-by point. The prototype FIM crew interface shown in Figures 1 and 2 consisted of two side-mounted electronic flight bags (EFB) and two ADS-B guidance displays (AGDs) mounted under the glare shield in the pilot's forward field of view. Figure 1 shows the position of a side-mounted EFB as well as a screen shot of the FIM application used for data entry and speed conformance monitoring. Figure 2 shows one of the AGDs used for the presentation of target and error speed values.

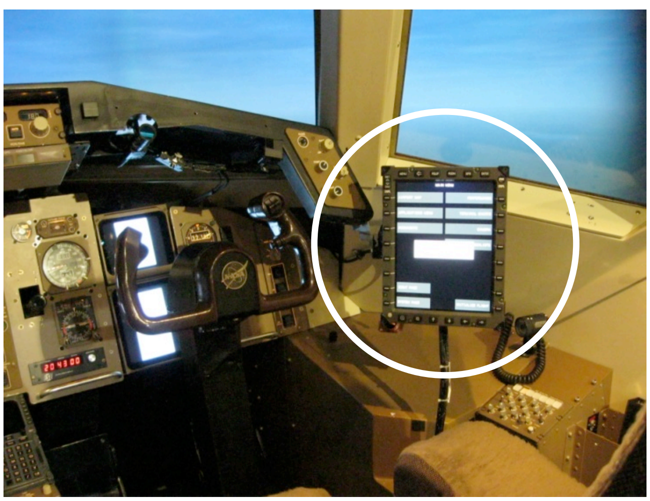

Figure 1. Side-mounted EFB and FIM application

Figure 2. AGD presenting target and error speed values

Previous FIM research conducted at NASA LaRC has utilized datalink to transfer information from ATC to the flight crew. However, since the ground infrastructure necessary to support datalink will not be available during the execution of near-term FIM operations, voice communications will be relied upon to transfer information necessary for FIM operations. In the IM-NOVA experiment, confederate controllers issued IM clearances to the flight crews, who then entered information into the EFBs, and activated the FIM avionics. The IM procedure required the flight crew to enter the following pieces of information included in the IM clearance into the EFBs.

- IM achieve-by point (i.e., FAF)
- Scheduled time of arrival at the IM achieve-by point
- Target aircraft callsign
- Assigned spacing goal (spacing interval required at the IM achieve-by point)
- Target aircraft flight path (arrival and transition)

Five flight scenarios were defined using the 1x5 experiment matrix shown in Figure 3 to allow an examination of five flight crew procedures.

1. The Nominal scenario consisted of an IM clearance issued by ATC prior to top-of-descent (TOD). After achieving the spacing goal, the subject aircraft maintained nominal FIM operations until reaching the achieve-by point.
2. During the Amend scenario, the initial IM clearance was issued shortly after TOD. Approximately two minutes after the spacing goal was achieved, ATC issued an amended clearance to increase spacing by 20 seconds.
3. In the Terminate scenario, the initial IM clearance was issued shortly after TOD. Once the pilot participants' aircraft and target aircraft were inside the DFW TRACON, ATC cancelled the IM clearance and vectored the target aircraft for landing on runway 13R. ATC then issued a new IM clearance with a new target for the pilot participants' aircraft.
4. The Suspend/Resume scenario consisted of an IM clearance issued by ATC prior to TOD. After the assigned spacing goal was achieved, ATC suspended the IM clearance and issued a speed change of 20 knots for the pilot participants' aircraft. Approximately two minutes later, ATC cleared the pilot participants' aircraft to resume IM spacing.
5. During the ADS-B Loss scenario, ATC issued the initial IM clearance prior to TOD. After the assigned spacing goal was achieved and both the pilot participants' aircraft and target aircraft were inside the TRACON, the target aircraft experienced a loss of ADS-B capability. The pilot participants notified ATC that they were IM Unable due to ADS-B loss by the target aircraft, and ATC then cancelled the initial IM clearance and issued a new clearance with a new target aircraft.

During all five scenarios, the closest aircraft in the arrival stream for the same runway as the pilot participants' aircraft was designated as the initial target aircraft. If a new target was designated later in the scenario, it was always the next closest aircraft in the arrival stream. For both the Terminate and ADS-B Loss scenarios, the second clearance was issued in the TRACON at an altitude below 10,000 feet.

Flight Crew Procedure	Nominal	Amend	Terminate	Suspend/Resume	ADS-B Loss

Figure 3. Experiment design matrix

Every crew flew each scenario twice – once with the captain as the pilot flying (PF) and the first officer as the pilot monitoring (PM), and once with the first officer as the PF and the captain as the PM. Therefore, each crew flew a total of ten experiment runs. The run order of the scenarios was partially counterbalanced, and within each crew the pilots switched PF and PM responsibilities between runs.

The pilot participants received training materials and had access to computer-based training prior to arriving at LaRC. After arriving at LaRC, pilot participants received four hours of classroom and hands-on training, with hands-on training involving the completion of three simulated flight training scenarios prior to completing the first data collection run. Each two-person crew participated in a two-day experiment session. The first day began with training, and then data collection flights were conducted, with each data collection flight lasting approximately 25 minutes. The second day consisted of the remaining data collection flights, followed by a post-experiment questionnaire and debrief session.

B. Pilot Participants

Pilot participants consisted of 10, two-person crews of current, qualified 757/767 pilots employed by major U.S. air carriers (i.e., a total of 20 commercial airline pilots). All pilots were male and ranged in age from 40 to 62 years. On average, each of the pilots had 23 years of airline experience and over 13,000 hours of commercial airline flight time. To minimize potential effects associated with different airline operating procedures, all two-person crews were paired from the same airline, and the pilots flew in their current operational position (Captain or First Officer) using their company's standard operating procedures (SOP) modified to include IM operations.

C. Scheduling and Spacing Technologies

This experiment utilized an integrated set of ground-based and airborne technologies consisting of TMA-TM, CMS decision support tools, and FIM avionics and procedures. These scheduling and spacing technologies are described below.

1. Traffic Management Advisor with Terminal Metering (TMA-TM)

TMA-TM is an extension of the operational TMA that determines an arrival schedule based on airport conditions, airport capacity, required spacing, and weather conditions. This scheduling tool calculates the Estimated Time of Arrival (ETA) and corresponding Scheduled Time of Arrival (STA) at various meter and merge points along the aircraft flight path. The TMA-TM data are broadcast to the en route and TRACON controller positions for use by the CMS tools to assist the controllers in maintaining optimum flow rates to the runways.

2. Controller Managed Spacing (CMS)

Three CMS tools were used during the IM-NOVA experiment to provide the confederate controllers with information needed to meet the TMA-TM generated schedule: early/late indicators, slot markers, and speed advisories. Early/Late indicators in the aircraft Full Data Blocks (FDB) enabled controllers to quickly assess the schedule-conformance information for that aircraft. Slot marker circles were used to indicate where an aircraft should be located at a given time if it were to fly the RNAV OPD, meeting all published speed and altitude restrictions. The relative position of the aircraft symbol and the slot marker provided a quick visual indication of how an aircraft is positioned relative to its scheduled time of arrival. Speed advisories in an aircraft's FDB helped confederate controllers formulate speed clearances for aircraft not performing FIM operations. The speed advisory provided a recommended Calibrated Airspeed (CAS) intended to place an aircraft back on schedule before reaching a scheduling fix.

3. Flight deck-based Interval Management (FIM)

The FIM tools provide onboard speed guidance to the flight crew, thus enabling them to achieve a precise spacing interval behind a target aircraft and thereby meet a schedule set by TMA-TM. In order to perform FIM operations during the IM-NOVA experiment, the simulator flown by the pilot participants was equipped with NASA's ASTAR algorithm (version 11.06.22) and a prototype FIM crew interface (see Figures 1 and 2). The ASTAR airborne spacing algorithm produces speed guidance by determining time-to-go until an aircraft and its target reach an achieve-by point along a 4-D trajectory.

D. Facilities and Equipment

This experiment utilized two facilities at NASA LaRC. Descriptions of each facility and its equipment are provided below.

1. Air Traffic Operations Laboratory (ATOL)

The IM-NOVA experiment used the LaRC ATOL, which operates a network of hundreds of real-time, medium-fidelity aircraft simulators. The simulation platform, known as the Airspace and Traffic Operations Simulation (ATOS), can be used for both batch and real-time human-in-the-loop experiments. Each aircraft simulator is referred to as an Aircraft Simulation for Traffic Operations Research (ASTOR), and ASTOR components include: a six degrees of freedom aircraft model, Primary Flight Display (PFD), Multi-Function Display (MFD), autopilot and auto-throttle systems, Flight Management Computer (FMC), Multi-function Control Display Unit (MCDU), Mode Control Panel (MCP), and ADS-B.[27]

The use of pseudo-pilot stations, which were developed to allow a single operator to control the basic functions of multiple ASTORs, was also required during the IMNOVA experiment. Two researchers used a total of four pseudo-pilot stations to control 24 ASTOR arrival aircraft that provided multiple air traffic flows into the DFW TRACON airspace. ATC controller stations using the Multi Aircraft Control System (MACS),[28] developed at

NASA ARC, were also integrated into the ATOL to enable confederate air traffic controllers to provide a realistic air traffic control environment. All controller positions used standard Display System Replacement (DSR) or Standard Terminal Automation Replacement System (STARS) displays augmented with CMS tools. Four recently retired DFW air traffic controllers served as confederate Center, Feeder, Final, and Tower controllers.

2. Integration Flight Deck (IFD)

The IFD is a full-scale simulator representative of a large commercial transport category aircraft and is driven by an appropriate aircraft dynamics mathematical model.[29] The cockpit includes standard ship's instruments representative of a line operations aircraft, and the cockpit's visual system is a panorama system that provides 200° horizontal by 40° vertical field-of-view. During the IM-NOVA experiment, all pilot participants flew the IFD, and the visual scene used was the DFW terminal environment in a daytime setting. The IFD simulator was also equipped with the ASTAR algorithm and the prototype FIM crew interface to enable the flight crews to perform FIM operations.

E. Dependent Measures

To assess the acceptability of the proposed ATD-1 flight crew procedures, qualitative data were collected in the form of acceptability, usability, and workload ratings via electronic questionnaires and a post-experiment debrief session. To assess the feasibility of the procedures, quantitative data were collected during each run, including spacing error at the FAF and the number and rate of speed commands issued by the airborne spacing algorithm. Although the achieve-by point was the FAF, the spacing error at the runway threshold was an additional metric of interest.

III. Results and Discussion

Results associated with the acceptability of the proposed ATD-1 flight crew procedures are presented in this paper. Additional details regarding the results of the evaluation of the procedures' feasibility are described in a companion paper.[25] For the following analyses and results, a sample size of 20 observations was anticipated for each scenario. However, data from one run of the ADS-B Loss scenario were excluded from the analyses due to simulation error.

A. Acceptability of Procedures

Pilot participants were asked to use a rating scale ranging from 1 ("completely disagree") to 7 ("completely agree") to respond to post-run questionnaire items intended to assess the acceptability of the ATD-1 flight crew procedures. It was hypothesized that the use of the procedures for receiving and executing IM clearances in a voice communications environment would be acceptable to the flight crew (i.e., that the pilot participants' mean ratings of the procedures' completeness and acceptability would be higher than a value of 4.5). This a priori hypothesis was tested using data collected in conjunction with the following two post-run questionnaire items:

a) The use of voice communications to provide the IM clearance(s) was acceptable in this scenario.

b) The flight crew procedures for the events in this scenario were complete and acceptable.

Descriptive statistics associated with the pilot participants' acceptability ratings are shown in the Tables 1 and 2, and statistical analysis was performed using the Wilcoxon signed rank test (i.e., a nonparametric test appropriate for analyzing ordinal data).[30] No statistically significant differences were found to exist between the mean responses obtained from the PF and PM for either questionnaire item in any scenario ($p \geq 0.236$), except for questionnaire item "b" in the nominal scenario ($p = 0.036$). In this case, the mean acceptability rating was slightly higher for the PM (mean = 6.9, SD = 0.3) than for the PF (mean = 6.5, SD = 0.9). For all five scenarios, both the PF and PM found the proposed ATD-1 procedures to be acceptable in a voice communications environment ($p \leq 0.002$).

Table 1. Descriptive statistics for acceptability ratings from post-run questionnaire item "a":

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.7	0.7	4	7	7	6.6	0.9	3	7	7
Amend	20	6.4	1.1	3	7	7	6.4	1.2	2	7	7
Terminate	20	6.8	0.9	3	7	7	6.6	1.0	3	7	7
Suspend/Resume	20	6.9	0.4	6	7	7	6.7	0.7	5	7	7
ADS-B Loss	19	6.2	1.5	2	7	7	6.1	1.6	2	7	7

Table 2. Descriptive statistics for acceptability ratings from post-run questionnaire item "b":

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.5	0.9	4	7	7	6.9	0.3	6	7	7
Amend	20	6.6	0.7	5	7	7	6.6	0.8	4	7	7
Terminate	20	6.7	0.6	5	7	7	6.6	0.9	3	7	7
Suspend/Resume	20	6.5	0.8	5	7	7	6.8	0.5	5	7	7
ADS-B Loss	19	6.5	1.0	4	7	7	6.3	1.4	2	7	7

B. Completeness of Procedures

An evaluation of the proposed ATD-1 procedures' level of completeness was based on pilot participant feedback obtained in response to the following three post-run questionnaire items:

c) The procedures did not contain missing steps.

d) The procedures did not contain extra steps that were unnecessary.

e) The procedural steps were logical and easy to follow.

It was hypothesized that the pilot participants would report that they found the procedures to be complete. That is, it was hypothesized that at least 90% of the pilots would report that they agreed with each of the statements associated with the post-run questionnaire items listed above.

The proportion of pilots who agreed with post-run questionnaire items "c," "d," and "e" are shown in Table 3. Using Fisher's exact test,[30] no statistically significant differences were found to exist between the proportion of PF and PM who reported the procedures were complete in any scenario ($p \geq 0.487$). Statistical analysis was performed using the binomial test of one proportion[30] to test whether the proportion of pilots who reported the procedures were complete was at least 90% versus whether the proportion of pilots who reported the procedures were complete was less than 90%. For all five scenarios, the proportion of pilots who reported that the procedures contained no missing steps, no unnecessary steps, and that the steps were logical and easy to follow was not significantly less than 90% ($p \geq 0.580$). This finding implies that the pilot participants felt that the proposed ATD-1 procedures were complete.

Table 3. Percentage (%) of pilot participants who reported procedures were complete:

Scenario	N	Questionnaire Item "c"		Questionnaire Item "d"		Questionnaire Item "e"	
		PF	PM	PF	PM	PF	PM
Nominal	20	95.0	100.0	100.0	90.0	95.0	100.0
Amend	20	95.0	95.0	95.0	90.0	100.0	100.0
Terminate	20	100.0	95.0	100.0	100.0	100.0	90.0
Suspend/Resume	20	95.0	100.0	100.0	100.0	100.0	100.0
ADS-B Loss	19	89.5	94.7	100.0	94.7	100.0	94.7
Exploratory	10	100.0	100.0	100.0	90.0	100.0	100.0

C. Pilot Workload

Pilot participants used the Modified Cooper-Harper (MCH) Rating Scale[31] to provide a workload assessment as part of the post-run questionnaire. It was hypothesized that the workload level required to execute the proposed ATD-1 procedures would be found to be acceptable (i.e., that a mean rating of less than "3" on the MCH scale would be reported, since a rating of "3" indicates that an instructed task is fair and/or has mild difficulty and that acceptable operator mental effort is required to attain adequate system performance.) It was also hypothesized that no increase in workload would be reported when the pilot participants completed the amend, terminate, suspend/resume, or ADS-B loss scenarios as compared to the nominal scenario (i.e., a difference of less than 1 unit on the MCH scale would be reported).

Descriptive statistics associated with the pilot participants' workload ratings are shown in Table 4, and statistical analysis was performed using the Wilcoxon signed rank test. There were no statistically significant differences between the mean responses from the PF and PM in any scenario ($p \geq 0.221$). For all five scenarios, both the PF and PM found the workload level required to execute the procedures to be acceptable ($p < 0.0005$). Furthermore, no significant increase in workload was reported for the amend, terminate, suspend/resume, or ADS-B loss scenarios as compared to the nominal scenario for either PF or PM ($p \leq 0.003$).

Table 4. Descriptive statistics for pilot workload ratings from post-run questionnaire:

Scenario	N	PF					PM				
		Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	1.6	0.7	1	1	3	1.5	0.6	1	1	3
Amend	20	1.6	0.6	1	2	3	1.3	0.5	1	1	2
Terminate	20	1.5	0.5	1	1	2	1.6	0.6	1	2	3
Suspend/Resume	20	1.5	0.7	1	1	3	1.5	0.6	1	1	3
ADS-B Loss	19	1.7	0.7	1	2	3	1.8	0.8	1	2	3

IV. Conclusion

The objective of ATD-1 is to showcase an integrated set of technologies that provide an efficient arrival solution for managing aircraft using NextGen surveillance, navigation, procedures, and automation for both airborne and ground-based systems. An integral part of any new technology is the procedures required to obtain the full benefit of the system. Given the delay in datalink technology infrastructure, the acceptability of FIM procedures in a voice communication environment is critical to the success of interval management in current day operations. In support of ATD-1, the IM-NOVA experiment was conducted to assess if procedures outlined by the ATD-1 ConOps, when used with a minimum set of FIM equipment and a prototype crew interface, were acceptable to and feasible for use by flight crews in a voice communications environment. Data were collected from 10 crews of current, qualified 757/767 pilots asked to fly a high-fidelity, fixed based simulator during scenarios conducted within an airspace environment modeled on the DFW TRACON area. Qualitative data obtained from pilot participants indicate that, for all scenarios completed during the experiment, the crew procedures used to receive and execute interval management clearances in a voice communications environment were found to be acceptable. The proposed procedures were found to be logical, easy to follow, and did not contain any missing or extraneous steps. Furthermore, for all experiment scenarios, the pilot participants rated the required workload level as being acceptable. As a result of conducting the IM-NOVA experiment, empirical data indicating that pilot participants found the IM concept and the proposed ATD-1 crew procedures to be acceptable are now available, and these data strongly suggest that ATD-1 crew procedures may be successfully executed in a near-term voice communications environment.

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